BRINGING CLOUDS INTO THE LAB

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Abstract We investigate experimentally the behavior of droplets in a fully developed turbulent flow, approximating the conditions inside clouds. The rate of collision of the droplets can be enhanced by turbulence. In this experimental study we focus on how droplet sedimentation in a homogeneous and isotropic turbulent flow affects the dynamics of droplets and their mutual interaction: collision, clustering and coalescence of droplets. These effects are monitored by measuring the temporal evolution of droplet size spectrum and also the detection of individual collision events. For this aim we are modulating the turbulence conditions and the dispersity of the droplet collection in the flow. In a truncated icosahedron (soccer ball) chamber with 20 air jets we generate controlled turbulence with specified properties (Reynolds number, dissipation rate, fluctuation velocity). Two different spinning disk droplet generators are used to generate different-size droplets. 3D-Particle Tracking Velocimetry (PTV) with Laser Induced Fluorescence (LIF) tagging is chosen as the experimental method to track the droplets and to detect the mutual interactions. In parallel, droplet size spectrum measurements are carried out using Phase-Doppler Anemometry (PDA). With these tools we will elucidate the interplay of turbulence and droplet interactions.

INTRODUCTION

An important process in cloud physics is the collisional growth of droplets in rainclouds [6]. Although it is well-known that turbulence enhances this process, there is no complete quantitative explanation of this phenomenon. Cloud turbulence is characterized by very large Reynolds numbers $Re_\lambda \sim 10^4$ (here Re_λ is the Taylor-scale Reynolds number) and dissipation rates $\varepsilon \sim 10 - 1000\ \mathrm{cm}^2/\mathrm{s}^3$. Besides nature, also many industrial applications involve such interactions of droplets.
We experimentally investigate droplet-droplet interactions in a turbulent flow. The present experimental setup is a quasi-spherical cavity, which is inspired by Refs. [4, 1]. The original setup by Hwang & Eaton [4] was a cubic cavity that has shorn corners to locate loudspeakers that drive the internal airflow. Chang et al. [1] found that an increased number of loudspeaker-driven jets leads to better homogeneity and isotropy with very small mean flows; they report a central region of about 50 mm in radius with homogeneous and isotropic turbulence. Therefore, we are also using many jets to drive the turbulence for better homogeneity and isotropy conditions, while trying to attain high Re_λ.

The turbulence characteristics are measured with a non-intrusive technique (PIV). The key parameters to be gathered from PIV are the magnitude u' of the velocity fluctuations and the dissipation rate ε. We follow the approach of de Jong et al. [2], who employ the Smagorinsky model [7] to calculate the sub-grid stresses from PIV measurements, to obtain realistic values for ε. The turbulent scales then follow from their definitions for homogeneous and isotropic turbulence, viz. the Taylor length scale $\lambda = \left(15\nu u'^2/\varepsilon\right)^{1/2}$, the Kolmogorov time scale $\tau_\eta = (\nu/\varepsilon)^{1/2}$ and Kolmogorov length scale $\eta = \left(\nu^3/\varepsilon\right)^{1/4}$) etc. In these equations ν is the kinematic viscosity of air. If we define ε with a correction constant C_ε as

$$\varepsilon = \frac{k^{3/2}}{\ell} = C_\varepsilon \frac{u^3}{\ell} \tag{1}$$

where $k = \frac{3}{2}u'^2$ is the turbulent kinetic energy, ℓ is the integral length scale and $C_\varepsilon = (3/2)^{3/2} \simeq 1.84$, then η can be expressed as

$$\eta = \left(\frac{\nu}{u'}\right)^{3/4} \left(\frac{\ell}{C_\varepsilon}\right)^{1/4} . \tag{2}$$

Here ℓ and η are related to $Re_\lambda = u'\lambda/\nu$ by $\ell/\eta = C_\varepsilon 15^{-3/4} Re_\lambda^{3/2}$. Thus Re_λ becomes

$$Re_\lambda = \left(\frac{15\ell u}{C_\varepsilon \nu}\right)^{1/2} . \tag{3}$$

When the ratio between the integral and Kolmogorov length scales is increasing, the turbulence intensity becomes more independent of the way it is stirred. Therefore, it is best to make the ratio as large as possible. At the same time, we want to maximize Re_λ to approach cloud-like conditions. An evaluation of these trends has led us to the current dimensions of the chamber, which has an internal diameter of almost a meter and has 12" subwoofers on the hexagon surfaces (20 surfaces) of the soccer ball. In total these speakers are consuming a power of 20 kW; about 0.2% of this energy is generating the turbulence. The 12 pentagon surfaces are in use for optical access and other practical purposes such as locating the droplet generators. Figure 1 shows a design sketch and the PVC frame that is the skeleton of the turbulence chamber. For illumination we use a pulsed 527 nm laser operating at 1 kHz with 28 mJ per pulse. This laser is illuminating a volume of 20x20x20 mm^3; four fast cameras are used for 3D-PTV.

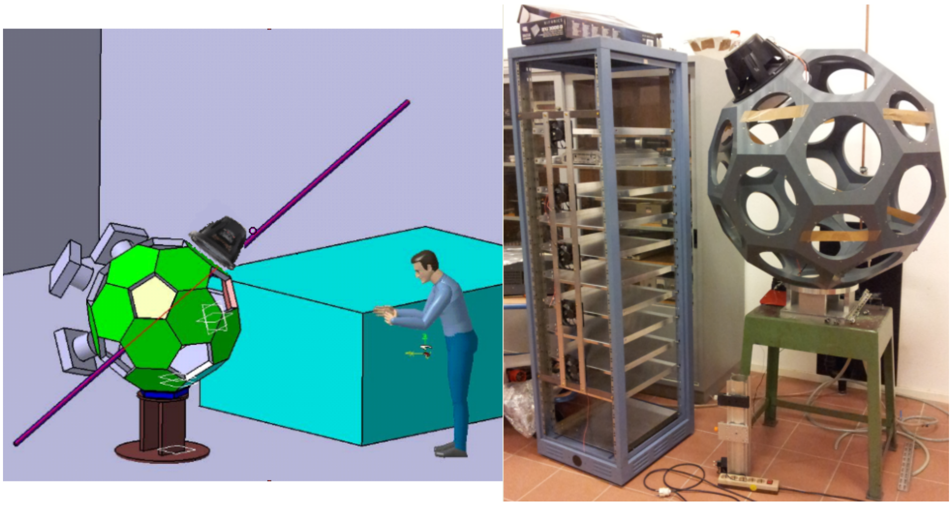

Figure 1. Sketch of the setup (left) and picture of the PVC frame that forms the backbone of the turbulence chamber (right).

FIRST RESULTS

We will briefly discuss the turbulence properties of the flow generated in our devices and compare these data with exisiting set-ups (both in Goettingen as in Eindhoven). As promising methods for the "inversion" of the droplet size spectrum to obtain the collision kernel have been reported [5] we will use this as the starting point of our quantitative investigations. We will present results of measurements on the temporal evolution of the droplet size spectrum with phase Doppler anemometry. We are preparing an experiment to investigate gravitational settling, collision and coagulation of droplets in homogeneous, isotropic turbulence by using complementary measurement techniques such as 3D-PTV [3], LIF and PDA. First preliminary results will be discussed.

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